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CAUSES AND DETERMINERS IN RADICALLY EXPERIMENTAL ANALYSIS

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EVEN where the experimental situation is clear, disagreement often exists as to the causes or determiners of given phenomena. For clearing the mind on such matters, as well as for guiding experimentation, the writer has found useful two rules of thought, which are here submitted. The bald statements of the rules will be followed by a commentary with illustrations.

Rule 1. Radically Experimental Thinking.—Test all questions or doubtful propositions as to causation, determination, explanation, by seeking mentally an experiment which, if carried out, would decide the matter. If no such experiment is conceivable, the question is one with which science can not deal.

Or: Reduce all questions to an experimental situation.

Rule 2. Causation of Differences.—In seeking causes or determiners, compare two cases and discover to what is due the difference between them. A cause or determiner is that which brings about the difference between two specifiable cases.

1. RADICALLY EXPERIMENTAL THINKING

What sort of knowledge is sought in the questions: How is this phenomenon caused or determined? How can we understand or account for this?

One of the things we desire to know is this: What conditions can be found which, if supplied, will produce the thing we are trying to understand; if changed or altered will change or do away with it? Finding conditions is called observation; supplying, altering or removing them is called experiment; this question therefore asks for conditions discoverable by observation and experiment. The search for and formulation of such conditions makes up a large part of the work of science; does the search for other sorts of conditions form any part of its work?

Men do indeed infer certain things confessedly not discoverable by observation or experiment, but these evidently deserve, and commonly receive, a classification by themselves, as something else than science; otherwise science itself would require division into experiential and non-experiential, the former including what is commonly practised as science. Our rule is the test for this classification; a question that could not be answered by any conceivable experiment (or series of experiments) does not belong to (experiential) science.

But what does "conceivable experiment" include and exclude? An experiment is a change in one or more of a given set of conditions; ideally carried out it involves the presence of two similar systems, known to act in the same way; on one of the systems a certain condition is then altered, and the difference this brings about is observed. In cases where this ideal can not be fulfilled, it forms the standard for mental reference with relation to the experiment as actually tried. The possibility of experimenting comes from the observed fact that conditions which sometimes occur or act together need not always do so. Now, a proposition to separate such conditions as are in the nature of things inseparable would not be a conceivable experiment. Is such a proposition involved in the question whether psychic processes affect physical ones?

But often a change in some one of a given or specified set of conditions is conceivable where it is not practicable. This may be for technical reasons; we have not obtained control of the conditions. Or the system under consideration may belong to past time. But in both these cases, when we assert that a specified condition is the cause of a certain result, we mean that if this condition could be or had been altered, as is done in experimentation, the result would have been different.

It is this mental reference to an experimental situation that is the essential point for clearing one's thought. Two diverse cases that require this clearing are of frequent occurrence. (1) A question expressed in general terms is so conceived by one person as to require for its answer a certain experiment, while another person understands it in such a way that it requires another experiment; thence arises argumentation at cross purposes. Clear statement of the problem as an experimental situation reveals at once that two diverse questions are under discussion, and gives either immediate agreement, or a method of solving the difficulty by experimentation.

(2) Questions or propositions as to causality or explanation are frequently so framed that they exclude an answer by any conceivable experiment in changing conditions. The attempt to state them as an experimental situation at once reveals that they do not belong to (experiential) science. Questions expressed in general terms are frequently so understood that no experiment or series of experiments could answer them, though the same questions may be so interpreted that they are answerable by experiment. When one side of a discussion understands the question in one of these ways, the other side in the other way, the resulting confusion is dispelled by the attempt to formulate the question as an experimental situation. Our second practical rule aids powerfully in clearing up such matters; it will therefore be taken up before passing to illustrations.

2. Causation as the Production of the Difference between Two Specified Cases

Nothing in science appears so productive of confusion and disagreement as attempts to state causes or determiners of things. Clearing of thought results if one adopts, at least as a preliminary measure, the rule to search for the causes or determiners of the *difference between two specified cases.*

The production of an event or a result requires, as a rule (at least in biology), the previous occurrence of a great number of conditions, alteration of any of which would change the result. Consider, for example, what an infinity of conditions must be fulfilled for the production of the brown color of a human skin or of a human eye; or for the swimming of an organism toward a window. Hence many minds revolt against the assertation that any particular thing x (a chromosome; a nucleus; a single physical agent, such as light) is the determiner or the cause for this result:—for it takes much more than the "determiner" to produce it. But other minds, apparently equally sane, persist in speaking of particular determiners or causes for exactly such cases. The difference is due neither to stupidity on one part or the other, nor to disagreement as to the experimental situation, but to a different conception of what is implied experimentally by "determiner" or "cause." One party thinks, when speaking of determination, of *everything necessary in order that the given result shall be produced;* so that "a determiner" would to him mean something supplying all these required conditions. The other means by a determiner *that which brings about the difference between a case that gives this particular result, and another which does not.* The first view insists that many things are necessary in order to produce the result; the second insists that if the "determiner" x is altered, the result is altered or done away with. Both are correct.

If one is seeking to understand, rather than to criticize or confute, the solution of the apparent disagreement lies in clearly distinguishing these two things, and in noting the meaning which underlies the proposition examined. The difference between a person with brown eyes and a similar person with eyes not brown may be decided or determined by something which by no means supplies all the conditions necessary for the production of the brown color. It takes an entire state to go to war, but a very small difference in the conditions may determine whether war or peace shall prevail. It might indeed be clearer if for the word *determiner* in such a meaning, some such name as "decider" were used, but it is important not to confuse a criticism of linguistic fitness with a denial of experimental facts. All the "determiners" spoken of in the formulations of Mendelian inheritance appear clearly to be such in the sense only of "deciders."

Conclusions deducible only from discovery of all the conditions necessary to produce a certain result must, of course, not be drawn from experiments showing a determiner only in the sense of "decider" between two possibilities; this appears not infrequent. Such illegitimate conclusions are perhaps most usually drawn when persons understanding determination in the first sense examine the statements of those that use the word in the second sense; this is a source of polemics.

Since to produce almost any result an indefinitely great number of preceding conditions, of diverse sorts, must have been fulfilled, and since neither thought nor practical investigation can handle all these at once, it becomes necessary to so analyze our problems that at a particular juncture only one cause or determiner (and that a definite one) need be sought. The key for this is the following principle:

A single sufficient determining factor can be found only for the difference between two cases.

With relation to this, several points must be grasped.

1. Evidently two cases may be so chosen that the difference between them is not due to a single determining cause. But by proper analysis problems can be brought (at least usually) to a situation where but a single determining cause *is* required; this is done by comparing cases that differ only in certain defined features; and in bringing the two cases closer and closer together, till finally the difference between them is due to but a single experimental cause.

2. For the difference between two cases that are di-

verse even in several respects, a relatively simple and unequivocal complex of causes can, as a rule, be discovered, so that the problem for investigation becomes clearly limited. But to search for all the causes of anything taken by itself is (in biology at least) a hopelessly indefinite and unlimited task.

3. Search for a single definite and unequivocal cause or determiner of a given result or characteristic has meaning only when there is at least implicitly a comparison with something else, for nothing is in itself completely and exclusively determined by any single preceding condition. What cause or determiner will be found depends upon what comparison is made. When the comparison is not specified, it may be made with diverse things by different minds; thence arise apparent disagreements. The cause or determiner of brownness of skin in man is some peculiarity of the germ cell, when we compare a given brown individual with a white one that has lived under the same conditions; it is exposure to sun when we compare a brown individual that has lived in the open with his in-door brother; if some other comparison is made, the cause is still different. It is really the difference between the two cases that we account for, and *both members of the comparison must be considered before the cause can be given.*

4. When seeking the cause of a given result, it may be unnecessary to state what we are comparing it with, because that is evident. But much obscurity and disagreement would be avoided if that were always made clear; the investigator himself should at least have thought through the comparison carefully.

5. While it is helpful if in experimentation the two cases compared can both be concretely present, for clearness of thought this is not indispensable. One of them may be supplied mentally.

6. By successively comparing our given case with others, taking first those which differ from it but little, and passing then to cases which differ from it in other re-

spects, and in a greater number of ways, the causal analysis may be carried to any extent desired. In this way is reached, so far as it can be reached, that complete statement of all the things on which a given process or result depends, with its accompanying "mental model" of the process,—that is commonly set forth as the aim of scientific investigation. At the same time, by classifying all the various sorts of preceding differences ("causes") and the corresponding succeeding differences ("effects"), we obtain general rules or laws.

7. But the statements or mental models of given processes referred to above can never be really complete in the sense of specifying everything that must have occurred in order that the given result should appear. For all differences between cases we find preceding differences, and so backward indefinitely. If this infinite regress appears unsatisfactory, it is the constitution of nature that is at fault. But any given investigation seeks, for definite purposes, to trace the determining differences back only to a certain stage. The investigator commonly finds that after a time the preceding difference of conditions passes into a field through which he is not interested in tracing it; as when a biologist finds a result to be due to a preceding difference in temperature.

8. Expressed accurately, the principle underlying all this is: *Every succeeding difference in perceptual conditions is experimentally bound up with a preceding difference in perceptual conditions.* This may be called *the* postulate of experimental analysis. Cause or determiner, and effect or thing determined, are both *differences* between specifiable cases. In common usage the term cause or determiner is loosely employed to express that which is added, or that which is subtracted, to produce one case from the other; it may, therefore, as well be the absence of something as the presence of something. Thus, the determiner for blueness of eyes, as compared with brownness of eyes, is, loosely, but con-

veniently expresed, the *absence* of something present in the germ cell that produced the brown eyes. The apparent absurdity of saying that something is determined by nothing disappears when we understand that this merely means that the *difference* between the given case (blue eyes) and some other (brown eyes) is due to the lack in the former of something present in the latter. This sort of analysis is necessary for all statements regarding determiners in Mendelian inheritance, and when properly carried out it reveals their true meaning and rids them of offense.

9. The question may be raised whether this way of looking at causation is a mere practical device for clearing thought in particular cases, or whether it has a wider significance. Is all causation only of differences? Is it only of differences that a causal explanation can properly be given? Is causal formulation inapplicable to things taken by themselves, without differentiation or comparison? Does all causal formulation necessarily imply comparison? It appears that all this might be affirmed; here the matter is raised merely as a question.[1]

3. ILLUSTRATIVE QUESTIONS FOR RADICALLY EXPERIMENTAL ANALYSIS

A. Some assert that a certain chromosome is a determiner of sex; others dissent.

What experiment or experiments would decide? Or has the word determiner here no experimental meaning? The positive assertion is evidently absurd if it is taken to mean that the chromosome contains all the conditions necessary for the production of the sex characteristics (male or female). Interpreted in accordance with our two rules, it means merely that if two similar eggs side by side produce animals of the same sex, and if from one of these a certain chromosome could be removed (or to one a certain chromosome could be added), this egg would now produce an animal of the other sex. The question is thus purely an experimental one. Of the enormous number of conditions necessary for the production of the sexual characteristics, this assertion specifies one, which happens to be practically interesting to us. We trace the *difference* in sex between two individuals back to a *difference* between the two eggs from which they came. We may then trace the difference between the eggs back to differences between the sperms; the latter to differences between the chromosome groups of the parents, and the process of tracing back is limited only by our knowledge. All these preceding differences (and any others that may yet be found to cause a *difference* of sex) are equally sex determiners; the discovery of one kind of sex determiner (in our sense of determiner) does not preclude the discovery of a thousand others.

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[1] Mills's "method of differences" set forth in his "Logic" is not the search for the causes of *differences between cases,* recommended above, but merely the examination of differences, as an aid to causal investigation of things taken by themselves.

B. Some assert that the brown color of the skin (or some other color characteristic) is hereditary; others dissent, asserting that it is due to oxidation of a certain chemical compound, or to exposure to the sun.

Applying rule 2, when we compare individuals that have lived under the same conditions and find one (*a*) dark, the other (*b*) white, we must conclude that the difference is hereditary, in the sense of determined by a *difference* in the germ cells. But this difference in the germ cells may be of such a nature as to prevent oxidation in one case, while permitting it in the other; it is then likewise true that the cause for the color is oxidation. The same individual *a* that is dark might perhaps not be so if not exposed to the sun; it is then true that exposure is the cause of the color. All these statements as to causes are elliptical, and all are equally true; at which one we arrive depends on what comparisons are made; what *differences* we are accounting for.

C. Some assert that the nucleus is the "bearer of the hereditary qualities"; others deny this with ridicule.

Making precise by means of our two rules this loose and obscure proposition, it means the following experimental situation. If two eggs side by side were identical in cytoplasm and in environmental conditions (throughout), but differed in their nuclei, the specified "hereditary qualities" produced would differ. If the assertion is that the nucleus is the *exclusive* "bearer," it further means that if two eggs side by side were identical in nucleus and in environmental conditions, but differed in cytoplasm, the specified "hereditary qualities" produced would *not* differ. The questions are experimental ones, of the highest interest, on which much work has been done.

But if the assertion is understood to mean that the nucleus contains all the conditions necessary for the production of the hereditary qualities; or if it means that the characters produced are independent of the environment—of course experiments already tried show its incorrectness. Only by reducing it to an experimental situation does it become a profitable question.

D. Some assert that the development of muscular tissue or of nervous tissue (or the like) is determined within the cells; others dissent.

This means that if the two cells were kept under same conditions, one would still produce muscle, the other nerve. It does not mean that the cell contains within itself all the conditions necessary for the production of muscle (or nerve); and it leaves open the question what the two cells would produce if they were kept under diverse conditions.

E. Some assert that the movement of a given organism is unequivocally determined by some external agent (as light); others dissent.

If the assertion is only that when two organisms are alike in internal and in other external conditions, a difference in the light on the two may unequivocally determine a difference in movement, it is correct. If, on the other hand, it asserts that when two organisms are subjected to the same conditions of light, an internal difference of condition may not equally unequivocally determine a difference in the movement (so that one may, for example, move toward the source of light while the other does not), it is incorrect. What is unequivocally determined is always a difference between two cases; what determines the difference depends on the comparison made.

F. Some assert that physical conditions affect psychic states, and *vice versa;* that the physical and psychical interact; others dissent.

To assert that physical conditions affect psychic states can mean only, from a radically experimental point of view, that a preceding alteration in an exclusively physical condition results in a change in a psychical condition (pain, sensation). The experiment appears to occur frequently, and to give as unequivocal results as any experiments in science (unless we suspect all physical changes to be accompanied by psychical ones, in which case we drop the radically experimental standpoint). (It will be observed that experimentation can have nothing to say on the question sometimes discussed as to whether the physical and psychic conditions occurring *at the same time* have a relation of cause and effect; this is a typical example of a question that can not be reduced to an experimental situation.)

The converse assertion is that a change in an exclusively psychical condition produces a change in physical conditions. The experimental situation is not a conceivable one, unless psychical changes *do* occur unaccompanied by physical ones.

G. Some assert that entelechy is required for determining what happens in development; others dissent.

The bearing that experiment can have on this question is to discover whether there ever occur cases in which two systems alike in all perceptual respects act in two perceptually different ways. If no such cases occur, no additional agent is experimentally demanded. If such cases do occur, the question whether entelechy is to be brought in is a non-experimental one.

4. Relation of Radically Experimental Analysis to Other Formulations

Radically experimental analysis thus reduces all questions to an experimental situation; seeks for every existing perceptual difference between cases to find a preceding perceptual difference on which the later one experimentally depends; and results in a formulation or explanation which includes only perceptual factors.

We often find, particularly in biology, formulations or explanations which are based on non-perceptual factors. This non-perceptual character is not always realized, nor readily detectible; it will be brought out by applying to the doctrine in question the two rules set forth above. In other cases the formulation confessedly includes non-perceptual factors; such is the vitalism of Driesch.

For clear thinking as to all such doctrines, confessed or unconfessed, a grasp of their relations to radically experimental analysis is essential. The crucial questions are: Can radically experimental analysis be carried through all parts of science, even biology? That is, can experimental causes be found for all that occurs? If so, are other sorts of causes likewise required? Is recourse to formulations including non-perceptual factors due to (1) a supposed lack of experimentally perceptible determining differences for all differences in results; or (2) to a mental need for some other conditions, *in addition* to the perceptual ones, to show perhaps "why" the perceptual conditions produce the results they do? Supplementary non-perceptual theories of the first sort, based on an assumed lack of perceptual determining factors, tend to discourage experimentation or the search for perceptual determining factors; while supplementary theories of the second sort have nothing to do with experimental science.

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